Collaboration networks and innovation in Canada's ICT Hardware Cluster

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Agenda

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- Small-world structure
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- Conclusion and discussion
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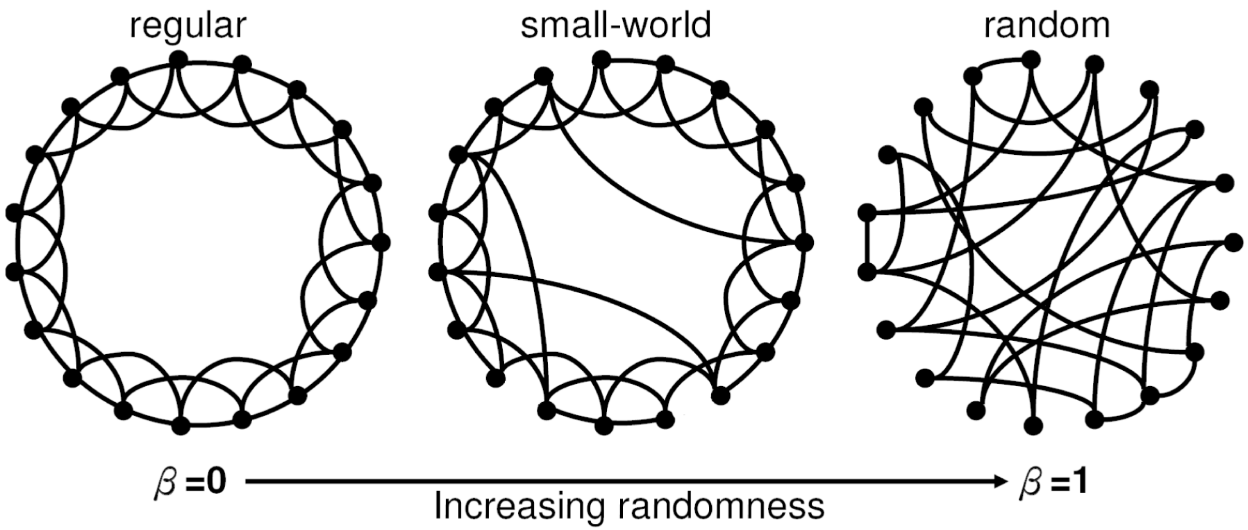
Research context

- ICT hardware products, such as microprocessors, electronic chips and fiber optics, are considered **General-Purpose Technologies** (GPTs)
- Since GPTs are connected to various segments of the economy, **coordination problems** have been an issue (Bresnahan & Trajtenberg, 1995)
- With the increasing complexity of technologies and products, it has led to the extensive use of **collaboration networks** by researchers and firms

Small-world structure

- Introduced by Watts and Strogatz in 1998, the small-world structure facilitates **information diffusion** through a network
- It enables dense and clustered relationships to coexist with distant and more diverse links in a network



Research questions

- At a researchers level, is the Canadian ICT hardware collaboration network characterized by a small-world structure?
- What is the impact of the industrial partnerships within the network on the collaboration dynamics?

Methodology

Data

- Collaboration links from the Natural Sciences and Engineering Research Council (NSERC) funding programs from 2003 to 2013
  - Links between academic principal investigator (PI) and co-applicants (researchers)
  - Links between PI and industrial partners (private firms and governmental organisations)

Social network analysis

- It offers a framework to test hypotheses and theories based on structured relationships with the help of mathematical measures and network structural properties (Nooy, Mrvar, & Batagelj, 2011)

Definitions

- **Giant component**: largest connected subgraph (component), i.e. that contains the majority of nodes

- **Betweenness centrality (g)**: measures the control that nodes have over paths in the graph. Typically, it favours nodes connecting communities (dense subnetworks). For a node *i*:

$$g(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

  - Where
    - σ_{st} is the total number of shortest paths from node *s* to node *t*
    - $\sigma_{st}(i)$ is the number of shortest paths from node *s* to node *t* passing by node *I*
  - Normalized value w.r.t. the maximum value observed in the graph (most central node = 1)

Definitions (con't)

- **Clustering coefficient**: measure of the degree of interconnectivity in the neighbourhood of a node (Watts & Strogatz, 1998)
  - Measures the extent to which one's friends are also friends of each other
  - For a graph G, the *local clustering coefficient* (cc_l) of a node *i* can be defined by:

$$cc_l(i) = \frac{nb\ pairs\ of\ neighbours\ connected\ by\ edges}{nb\ pairs\ of\ neighbours}$$

  - The clustering coefficient for the entire graph G, $cc_l(G)$, is the simple average of $cc_l(i)$ for all *i* within V

Definitions (con't)

- **Average path length**: average number of edges along the shortest paths for all possible pairs of nodes in the network
  - Measures the efficiency of information diffusion within a network
  - If $d(i_1, i_2)$ represent the shortest distance between node i_1 and node i_2 in the graph G, the average path length (l_G) is calculated using:

$$l_G = \frac{1}{n(n-1)} \sum_{i \neq j} d(i_1, i_2)$$

Definitions (con't)

- **Small-world networks** are characterised by a high clustering coefficient combined with a short average path length
  - A way to determine if a graph has a small-world structure is to compare its properties to those of a random graph of the same size

$$\frac{l_G}{l_{rd}} \approx 1 \quad and \quad \frac{cc_l(G)}{cc_l(rd)} \gg 1$$

- **Small-world variable (SW):** a high SW (much greater than 1) confirms the small-world structure

$$SW = \frac{\frac{cc_l(G)}{cc_l(rd)}}{\frac{l_G}{l_{rd}}}$$

Networks construction

- Gephi software was used to construct and visualize the collaboration networks of the researchers as well as measure the structural network and small-world variables
- 5-year moving windows over 2003-2013 periods, resulting in 14 distinct undirected networks (7 researchers networks and 7 researchers-organizations networks)
- Measures are taken on the giant components because the networks are highly disconnected

NSERC Networks: Research Collaboration

ICT Hardware related projects

Network composition

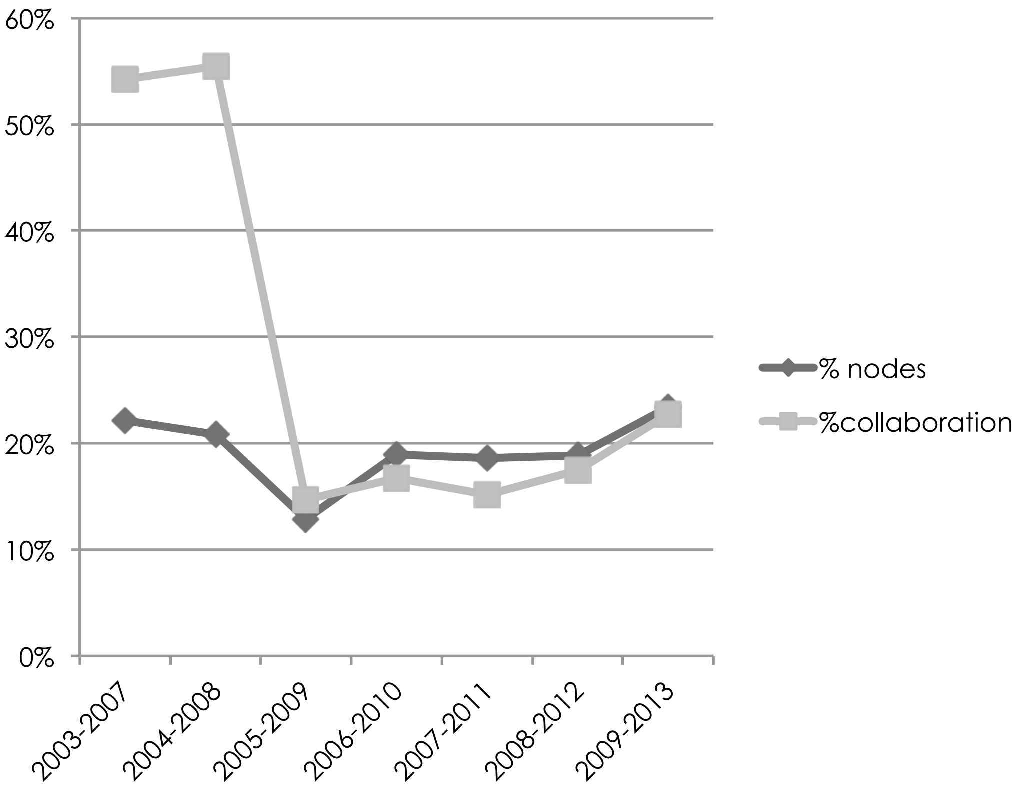


Figure 1: Evolution of the composition of the largest component

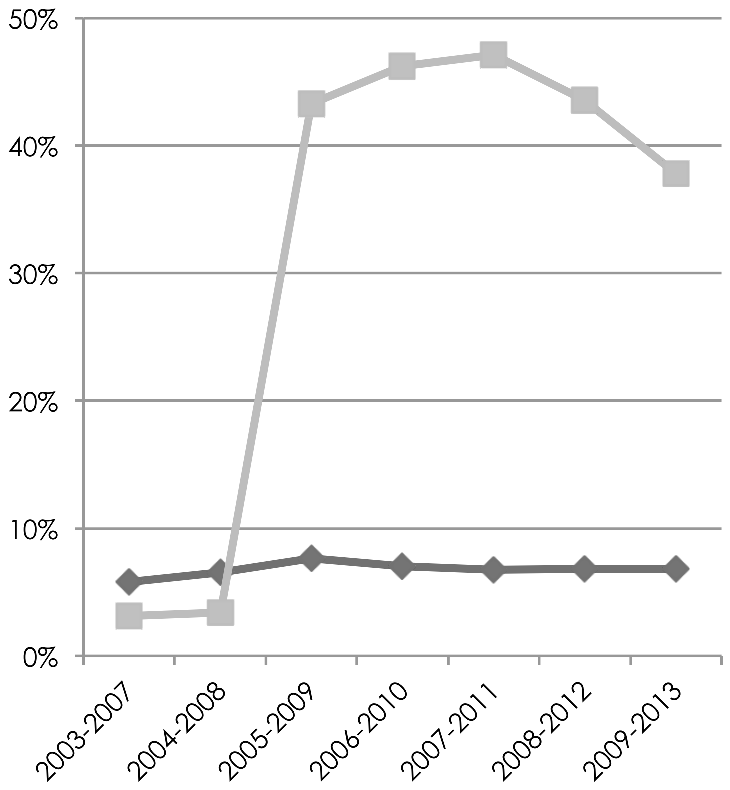


Figure 2: Evolution of the composition of the second largest component

Example of the 2008-2012 network

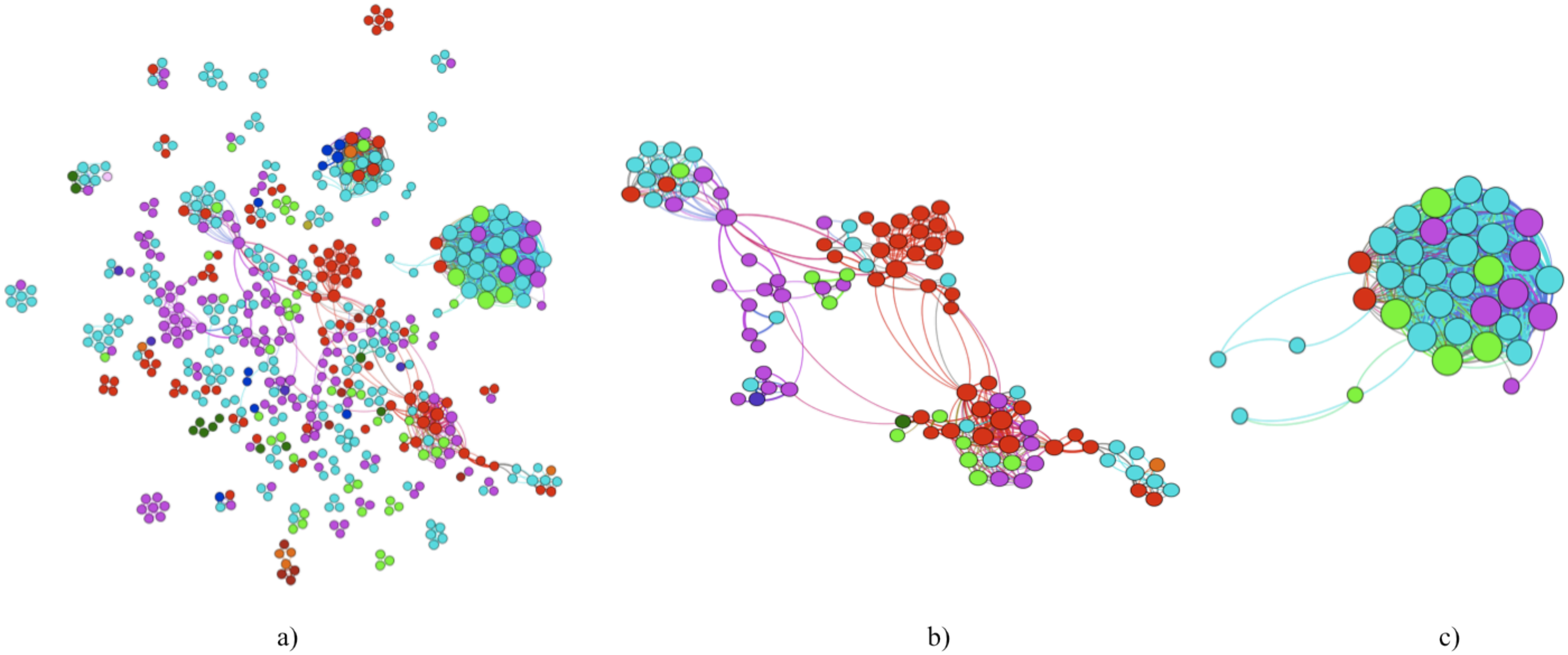


Figure 3: a) 2008-2012 full network, b) its largest component and c) its second largest component

Network size (# of nodes)

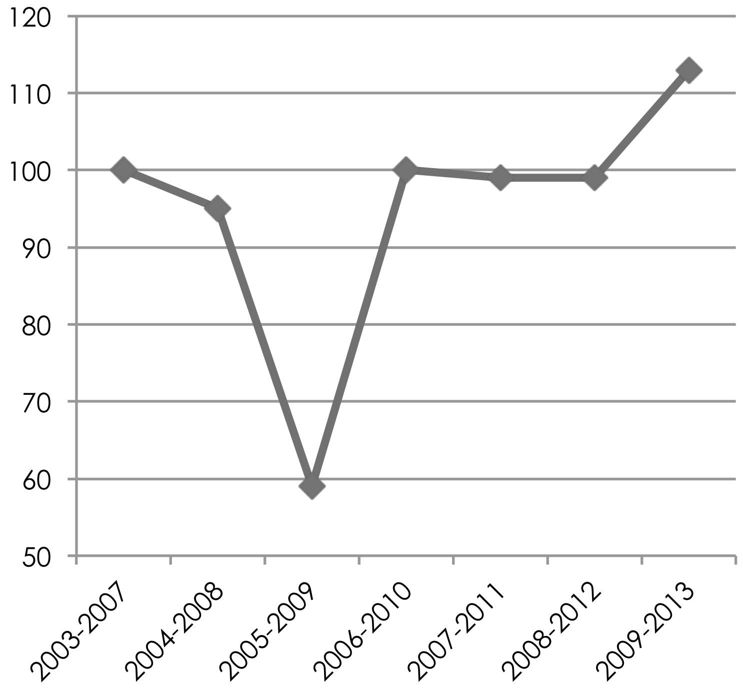


Figure 4: Evolution of the size of the largest component

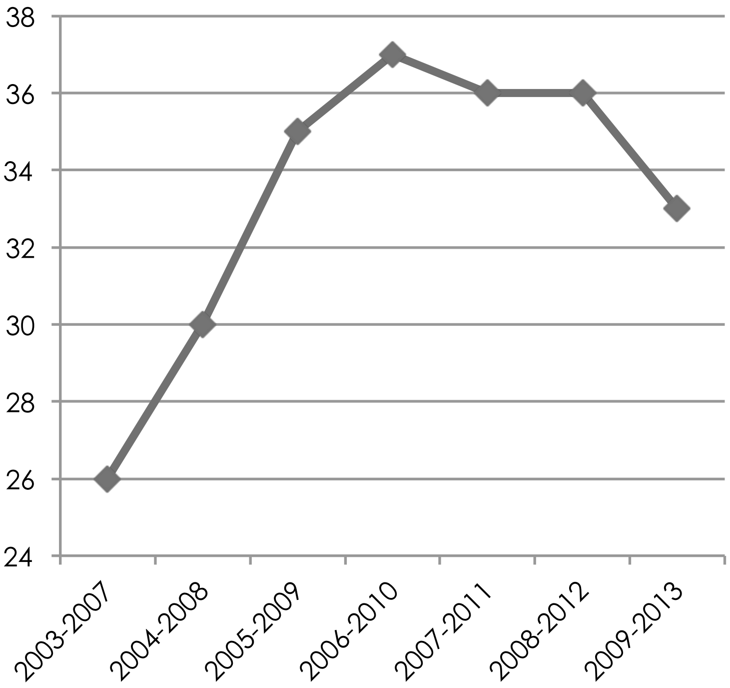


Figure 5: Evolution of the size of the second component

Small-world analysis

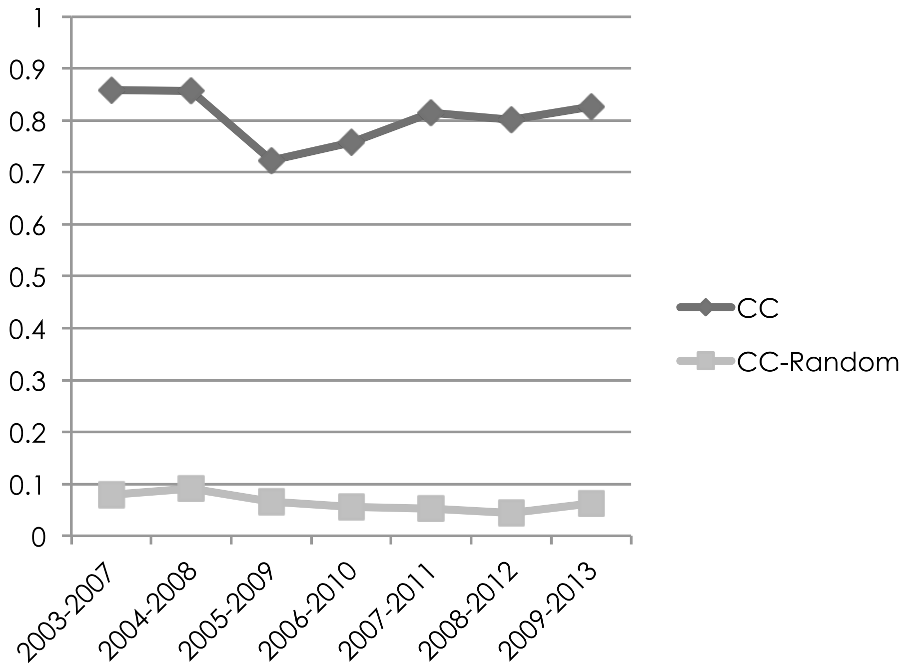


Figure 6: Clustering coefficient of the collaboration and random networks

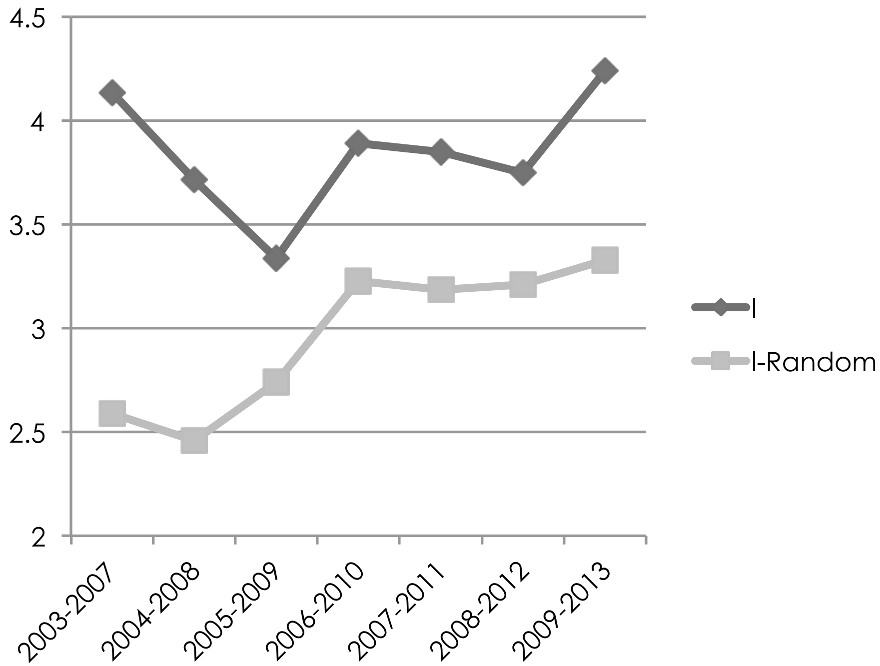


Figure 7: Average path length of the collaboration and random networks

Small-world analysis (con't)

Table 1: Small-world properties for the largest component

Period	Network size	l/l(rd)	CC/CC(rd)	SW
2003-2007	100	1.597	13.438	**8.413**
2004-2008	95	1.511	12.478	**8.260**
2005-2009	59	1.217	10.955	**9.000**
2006-2010	100	1.206	13.518	**11.208**
2007-2011	99	1.208	20.450	**16.925**
2008-2012	99	1.168	19.048	**16.309**
2009-2013	113	1.274	23.382	**18.356**

The small-world properties of the giant component are increasing over time

Small-world analysis (con't)

Table 2: Small-world properties for the second largest component

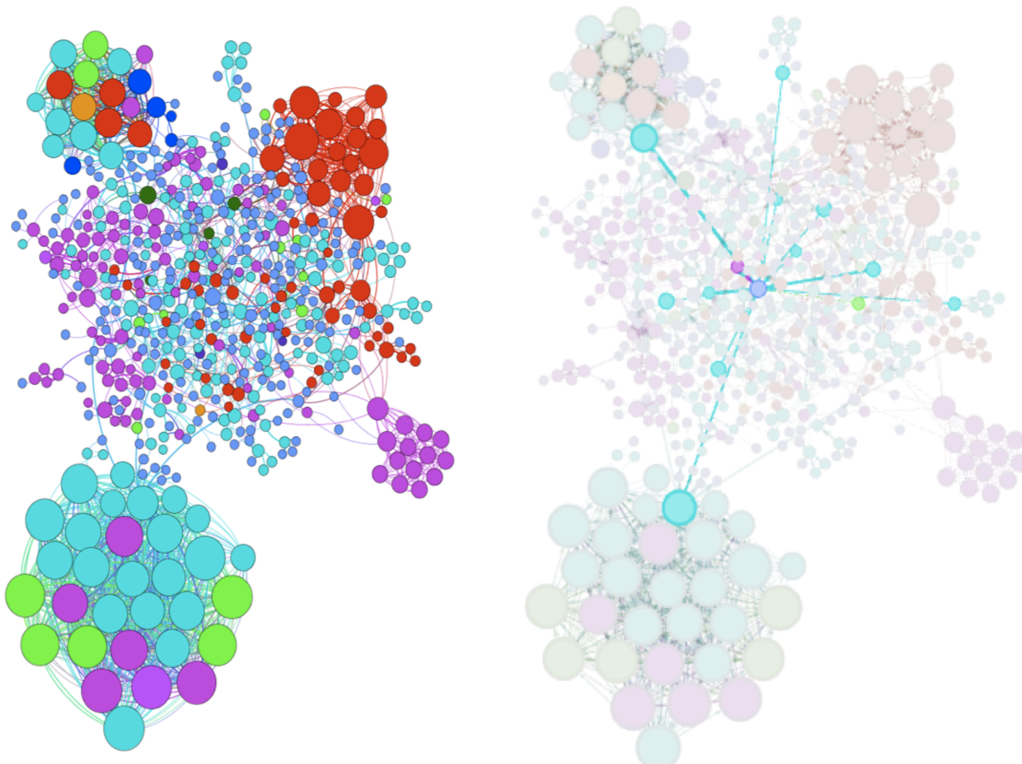
Period	Network size	l/l(rd)	CC/CC(rd)	SW
2003-2007	26	0.774	14.850	**19.193**
2004-2008	30	1.039	24.458	**23.546**
2005-2009	35	0.894	1.932	**2.160**
2006-2010	37	0.918	2.014	**2.194**
2007-2011	36	0.894	1.696	**1.896**
2008-2012	36	0.894	1.738	**1.943**
2009-2013	33	0.835	1.543	**1.848**

The second component losts its small-world properties when changing composition during the 2005-2009 period

NSERC Networks: Researchers-organisations Collaboration

ICT Hardware related projects

Impact of adding industrial partnerships



a) b)

Figure 9: a) Largest component for the 2009-2013 researchers-organisations collaboration network (organisations are coloured in violet) and b) highlighted connections of an organisation within the network linking multiple subgroups of researchers

Betweenness centrality (firms)

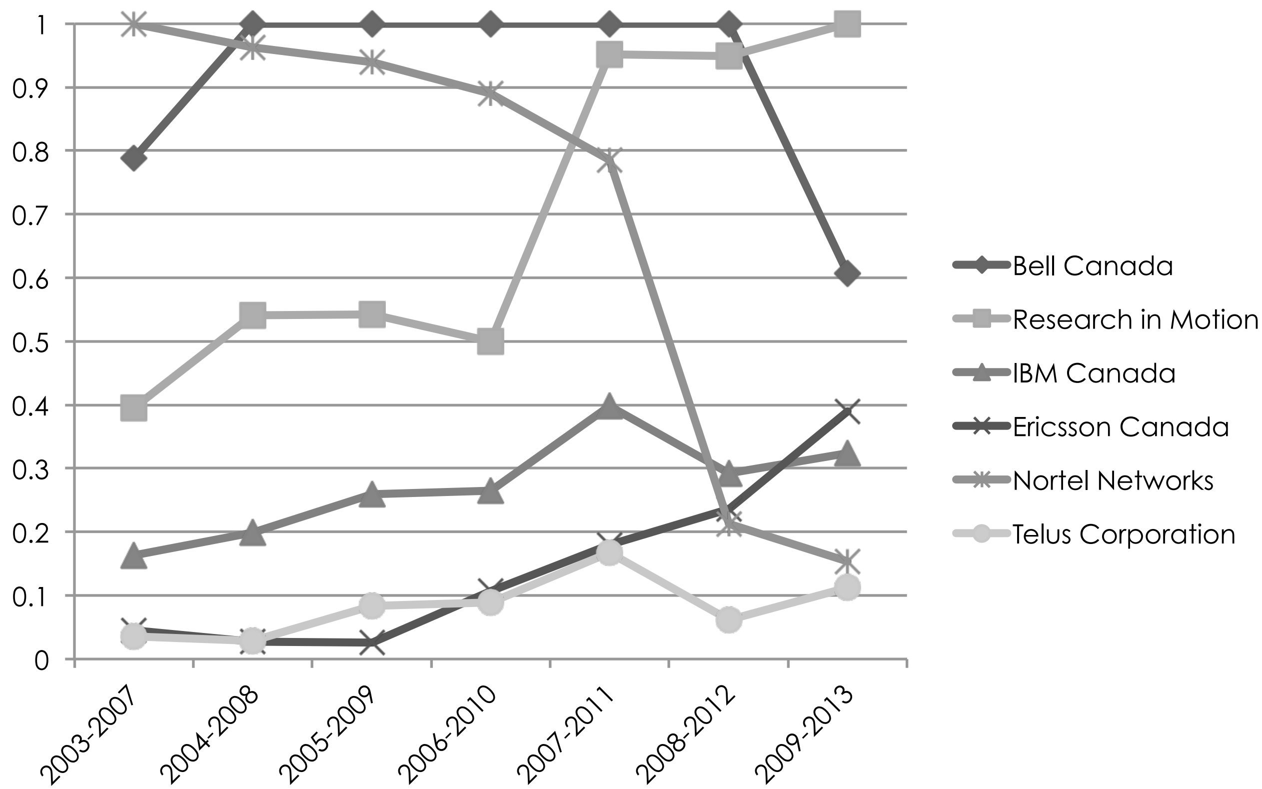


Figure 10: Evolution of normalized betweenness centrality for key firms of the researchers-organisations network

Betweenness centrality (public organisations)

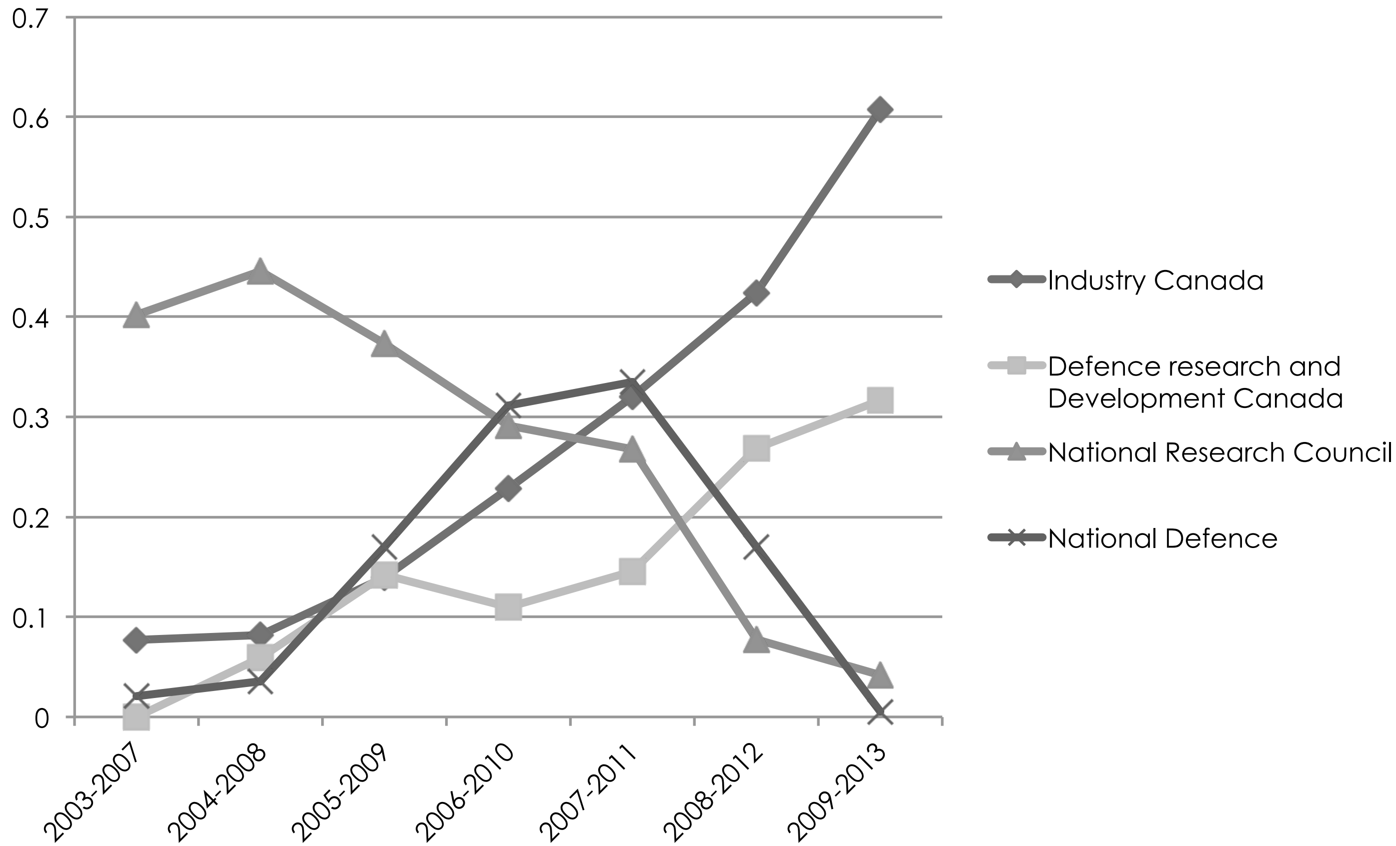


Figure 11: Normalized betweenness centrality for key public organisations in the network

Small-world analysis

Table 3: Small-world properties for the largest component of the researchers-organisations collaboration networks

Period	Network size	CC/CC(rd)	l/l(rd)	SW
2003-2007	493	215.00	1.06	**202.13**
2004-2008	512	138.67	1.04	**133.74**
2005-2009	542	85.80	1.13	**76.02**
2006-2010	636	71.50	1.07	**66.74**
2007-2011	669	146.33	1.24	**118.36**
2008-2012	663	49.00	1.15	**42.70**
2009-2013	687	119.67	1.11	**107.73**

Collaboration with firms emphasizes the small-world structure

SW comparison

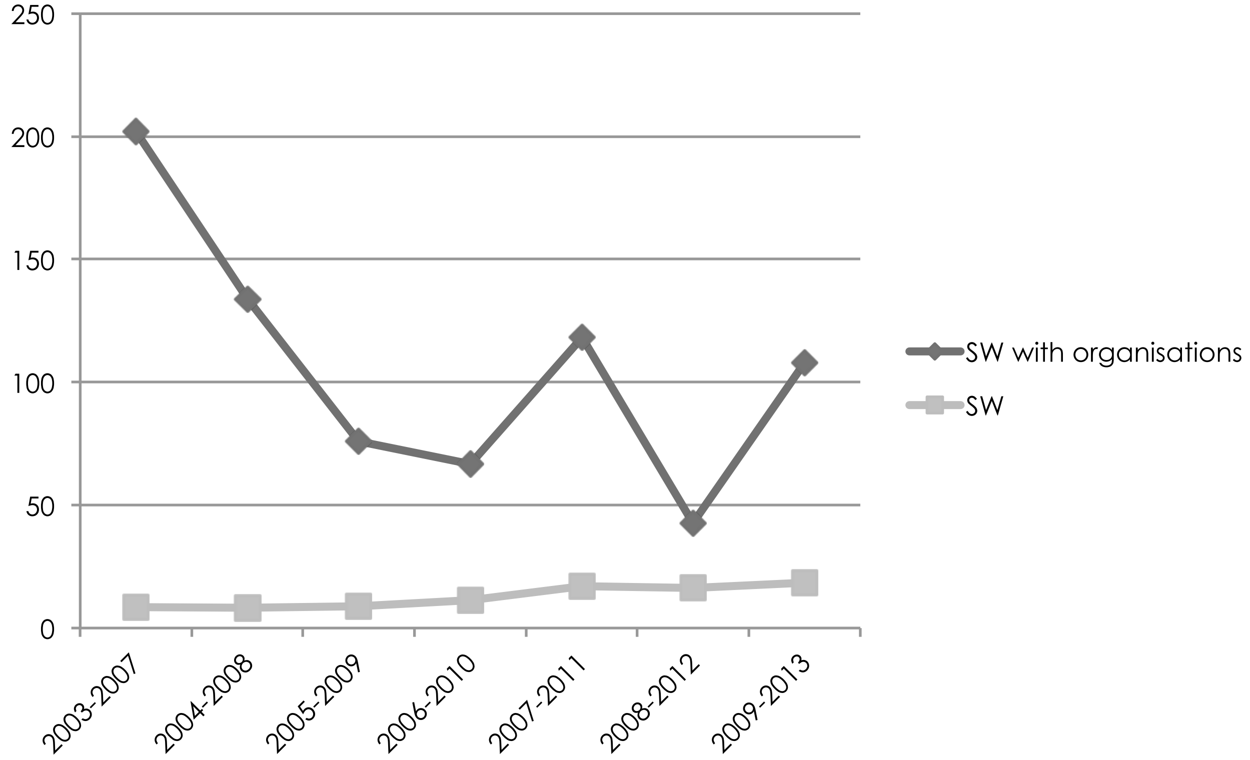


Figure 12: SW evolution for the two sets of networks (researchers only and researchers-organisations)

Conclusion and discussion

Conclusion

- Research collaboration networks are highly disconnected
- Giant component shows small-world properties leading to optimal information transfer
- Organisations (private and public) are highly central (in terms of betweenness) and allow a significant increase in SW value while connecting researchers sub-components

Next steps

- Adding collaboration data
  - Patents and publications
  - Mitacs collaboration links (access being negociated)
  - Intra-firm collaboration
- Determine the impact of network structure on innovative performance

Thank you